7919-26-T

USE OF IMAGE INTENSIFIERS FOR REAL-TIME MULTISPECTRAL VIEWING

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Prepared for the Advanced Research Projects Agency, Washington, D. C., ARPA Order No. 774, and administered by the Night Vision Laboratory of the U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, under Contract No. DA-44-009-AMC-1494(T).

28

NOTICES

Sponsorship. The work reported herein was conducted by the Willow Run Laboratories of the Institute of Science and Technology for the Advanced Research Projects Agency, Washington, D. C., under ARPA Order No. 774. This project is being administered by the Night Vision Laboratory of the U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, under Contract No. DA-44-009-AMC-1494(T). Contracts and grants to The University of Michigan for the support of sponsored research are administered through the Office of the Vice-President for Research.

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FOREWORD

This project comprises studies of the use of night vision aids in counterinsurgency. All the aids with which it has been most directly concerned have made use of direct-viewing image-intensifier tubes.

The investigation discussed herein came about as a result of our curiosity regarding the possibility of obtaining true-color viewing instead of the usual monochromatic output with these image intensifiers. It has been conducted with low priority and with a bare minimum of equipment. Progress is now at the point where potential value of the technique should be assessed and the continuing program planned accordingly.

The project code number for this work is AMSEL-NV-I. The project engineer is Walter R. Lawson, U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia.

ABSTRACT

An experimental program has investigated the practicality of synchronized rotating filter wheels at the input and output of an image intensifier to produce a field-sequential color image. Both military and commercial intensifier tubes were used. Reasonably true-color rendition was obtained, even with the limitations imposed by crude equipment and far-from-optimum filters. Fundamental limitations result in rather large energy losses and hence preclude full-color operation at very low light levels (such as starlight). At intermediate light levels, color viewing may be practical and may be valuable in enhancing target contrast.

With appropriately chosen sets of input and output filters, the spectral response of camouflage detection film can be duplicated. This makes the near-infrared reflectance of the scene visible by translating that portion of the spectrum to visible red. Red input energy is presented as green in the image, and green input is presented as blue. These translations make green vegetation appear in striking contrast to man-made objects which to the unaided eye seem to match closely. This suggests the possible use of this simple device for real-time reconnaissance, with appropriately chosen filters and spectral translations to enhance specific target classes. The obvious advantage over camouflage detection film is that this device operates in real time. Also, the spectral translation characteristic may be readily varied.

The promising experimental results suggest that a supplemental program should be supported: a better, more flexible, and more portable model should be built: and available spectral reflectance data should be analyzed to help select optimum filter combinations.

CONTENTS

FIGURES

USE OF IMAGE INTENSIFIERS FOR REAL-TIME MULTISPECTRAL VIEWING

1
BACKGROUND

1.1. IMAGE TUBES

A direct-viewing image-converter (intensifier) tube, hereafter referred to as an image tube, is a relatively simple device. A single-stage image tube consists of an evacuated cylindrical housing with a glass window at each end. The window at the input end is internally coated with a light-sensitive photoemissive material known as a photocathode. The window at the output or viewing end is internally coated with a fluorescent material commonly referred to as a phosphor.

In operation, an image is focused onto the photocathode by optical means. Light energy incident upon the photocathode causes the release of electrons, which are accelerated by an external power source and are focused to impinge upon the phosphor. Upon striking the phosphor, the electrons give up their acquired energy, which is converted to light output. In this manner, an intensified image is produced on the phosphor for direct viewing or for photographic recording (see fig. 1).

Two of the more important parameters of image tubes are luminous gain and resolution. The luminous gain of an image tube is usually defined as the ratio of the total luminous flux exiting from the phosphor to the input flux on the photocathode. This gain is commonly ex-

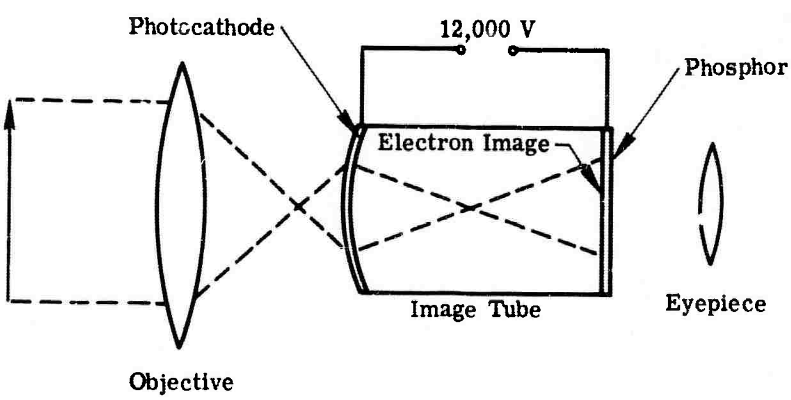

FIGURE 1. IMAGE-TUBE CONVERSION PROCESS

pressed as the ratio of output power per unit area in the visible spectrum (determined by the phosphor) to the input power per unit area measured across a stated spectral bandwidth. The spectral distribution of the source must also be specified, of course. For multispectral work, it is desirable to know the narrowband gain as a function of input wavelength. This function is normally of the same shape as the curve of photocathode efficiency. Single-stage gains typically range from about 10 to somewhat over 100.

Resolution is usually specified as a minimum resolution in line pairs per millimeter at the center of the screen. It is usually measured by the manufacturer with commercial modulation-transfer-function apparatus, although in some cases a resolution chart is employed.

A typical single-stage electrostatically focused tube with a 25-mm-diameter screen, for example, will resolve a minimum of 25 line pairs per millimeter over a diameter of only about 8 mm. Near the periphery, the resolution falls to less than 10 line pairs per millimeter.

Magnetically focused tubes achieve somewhat higher and more uniform resolution by means of a coaxial focusing coil or large permanent magnet. They do so, however, at the expense of an increase in size, weight, power consumption and cost.

Cascaded magnetically focused commercial tubes are available which offer very good performance. These tubes, however, require large high-current focus coils, or heavy permanent magnets, which limit their application to fixed rather than portable operation. Luminous gains of 35,000 and resolutions of 25 line pairs per millimeter can be achieved.

Single-stage electrostatically focused tubes may be cascaded in order to achieve higher luminous gain. The best present-generation multistage electrostatically focused tubes are classified by the military.

Second- and third-generation tubes featuring secondary emission channels and solid-state techniques are being developed by several manufacturers. References 1 and 2 discuss image tubes, characteristics, and some applications.

1.2. PHOTOCATHODE MATERIALS

Photocathode materials commercially available are selectively sensitive in the region from about 1000 Å to above 12,000 Å. This region covers the entire visible region of the spectrum and parts of the near-ultraviolet and near-infrared regions. Characteristic curves of some of these materials [3] are shown in figure 2. The S-20 photocathode is currently used in most night vision devices because of its high efficiency and wide spectral range. This type material is also available in an "extended-red" variation. As its name implies, its near-infrared response is better than the published curves of the S-20 material indicate.

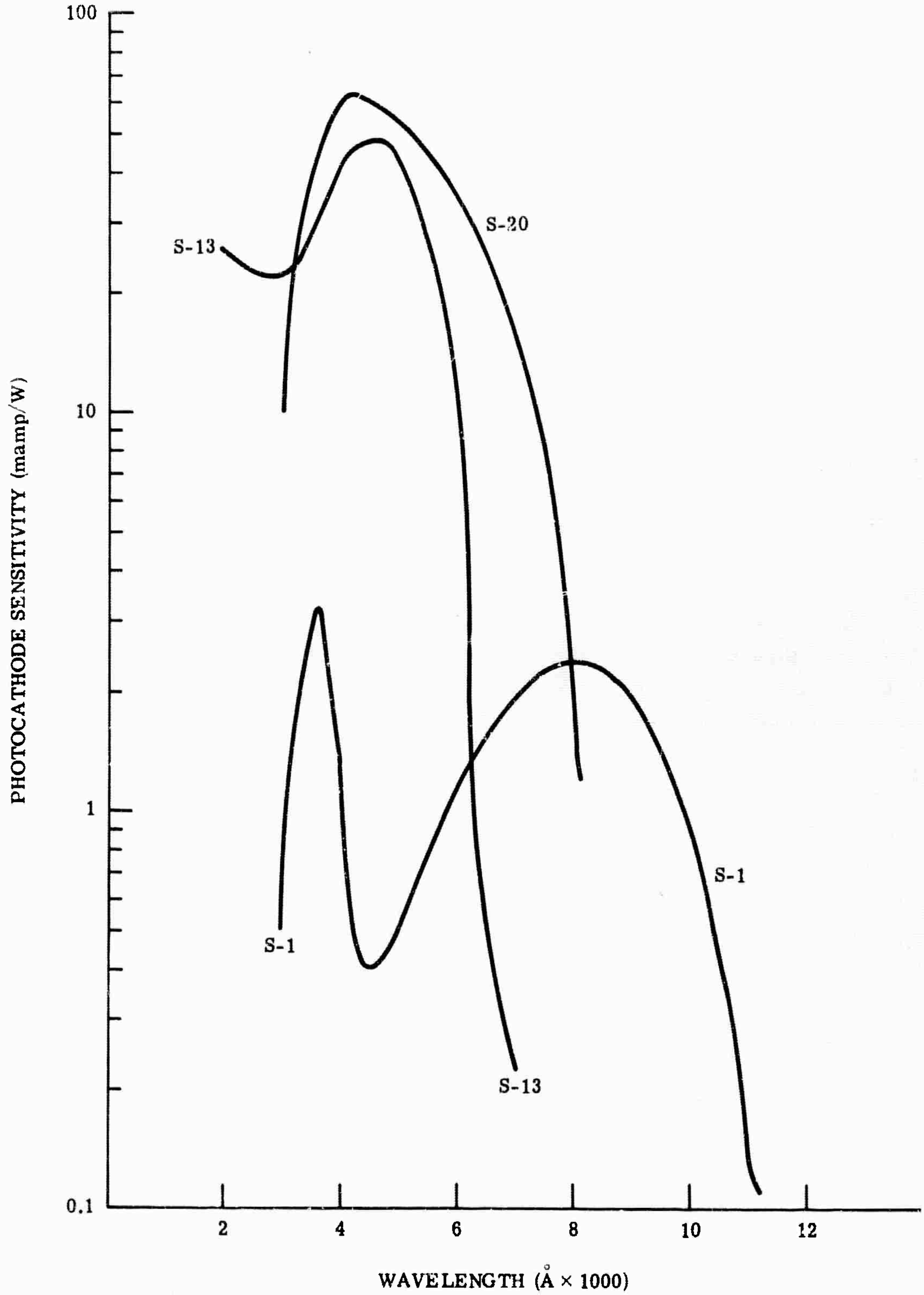

FIGURE 2. TYPICAL ABSOLUTE SPECTRAL RESPONSE CHARACTERISTICS OF PHOTOEMISSIVE DEVICES

Premium photocathodes are under development; these are essentially flat from 4000 to 10,000 Å. These materials are considered proprietary by their producers, however, and curves are not available for publication.

1.3. PHOSPHORS

There are at present more than 30 registered phosphors which range in color from a deep blue (P-11 and P-16) for photographic purposes to red (P-22R) for color TV use. In addition to color, each of these phosphor materials has such other pertinent characteristics as persistence (rate of decay), sensitivity, resolution (grain size), and efficiency, all of which must be taken into consideration with respect to specific applications.

At present, most direct-viewing tubes feature the P-20 phosphor, which is green and radiates in a narrow band around 5500 Å. It was selected because of its high efficiency when coupled to the human eye. Thus, a scene viewed with a typical image tube will appear in shades or tones of green.

Figure 3 shows the characteristic curves of some commercially available phosphors.

In the various military night vision aids, the image tube is used to make it possible for the observer to see better at low light level. Energy over the entire bandwidth to which the photocathode is sensitive is used to produce an image in the spectral region to which the eye is most sensitive (P-20 phosphor: green).

It is important to remember that the image tube does more than just "amplify light," i.e., produce an output image that appears brighter than the input. It also, in general, changes the spectral distribution of the incoming light. The output spectral distribution is determined by the phosphor characteristic and is unrelated to the input spectral distribution. The input spectral sensitivity is determined by the photocathode characteristics and has no effect on the input spectrum. Thus, the image intensifier may be used to make images formed by energy from outside the visible spectrum visible to the human eye. Likewise, energy from any narrow spectral band may be selected for observation by the use of a bandpass filter at the input to an intensifier tube.

From the above considerations, it is a simple step to the concept of producing multicolor images with an image tube. Figure 4 is a schematic of a system which makes use of two synchronized rotating filter wheels to select sequentially a series of input-output filter combinations. The result is a field-sequential color system very reminiscent of the now-obsolete CBS color television system [4, 5, 6].

To produce a colored output image, the output phosphor must, of course, contain all desired colors and ideally would appear white. Three sets of filters should produce reasonably true-color rendition. The three colors would then be the three additive primaries: red, blue, and

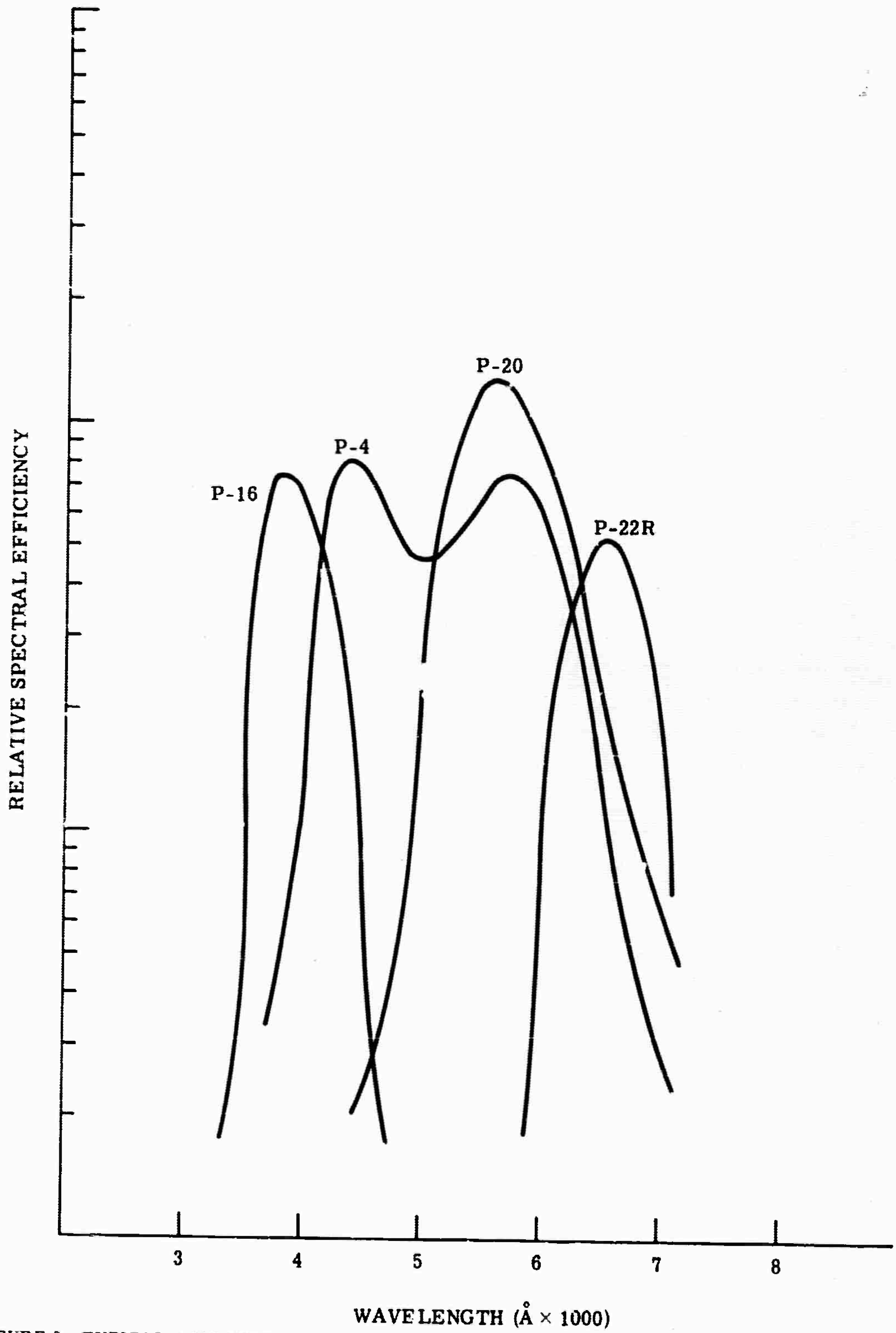

FIGURE 3. TYPICAL ABSOLUTE SPECTRAL RESPONSE CHARACTERISTICS OF ALUMINIZED PHOSPHOR SCREENS

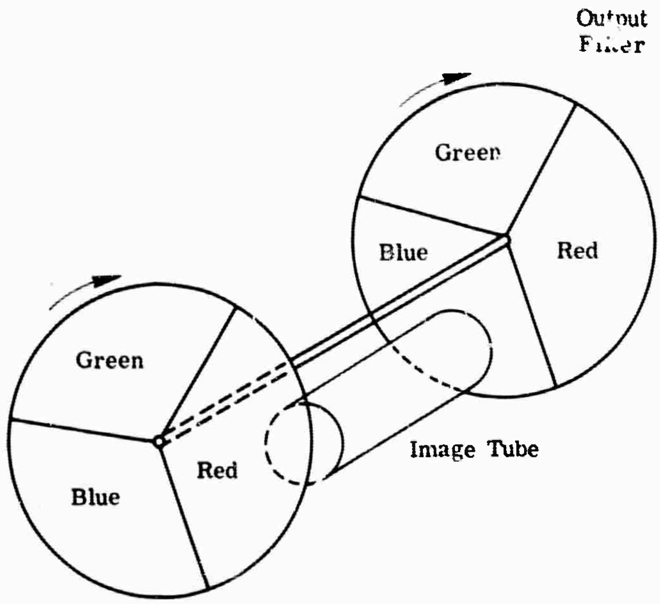

FIGURE 4. SKETCH OF MULTICOLOR SYSTEM

green. Incoming energy would be separated into the three spectral components, and each would be reproduced, after passing through the image intensifier and output filter, in its original color. If the filter wheels are rotated above the visual fusion speed (perhaps 20 rps) the result will be a reasonably true-color reproduction of the original scene.

The experimental program described in the following section was undertaken to explore the practicality and potential usefulness of this technique.

2
EXPERIMENTAL PROGRAM

This work has been performed with low priority on a very limited budget. Accordingly, relatively crude apparatus and components already available within the laboratory were used wherever possible.

Three image tubes were available. These were:

1. A three-stage type 8586 tube having an S-20 photocathode and a P-20 phosphor. This is the tube used in the Starlight Scope.* For these experiments, the entire scope, including its optics and power supply, was used.

*A classified rifle sight used for night viewing.

2. A type 6914 single-stage self-focusing tube with an S-1 photocathode and a P-20 phosphor.

3. An RCA type C73429G single-stage self-focusing tube obtained on loan from the National Aeronautics and Space Administration. This tube is identical with the 6914 except that it has an S-20 photocathode.

In order to utilize these tubes, a simple test fixture was assembled. This fixture served to hold the Starlight Scope or either of the single-stage tubes as desired. It also provided a mount for a pair of synchronously driven filter holders, one in the input plane, the other in the output plane. A light-tight box covered the entire apparatus in order to prevent stray light from reaching the photocathode. This test fixture and a spare 6914 tube are shown in figure 5. A surplus objective lens (f/2.1, 4-in. focal length) and a surplus eyepiece lens (40-mm focal length, 20-mm diameter) were utilized for the system optics with the single-stage tubes.

2.1. TRUE-COLOR DISPLAY

One of the first experiments performed was directed toward determining whether the Starlight Scope could be modified to present true-color scenes in low-light-level environments. Because of its green viewing phosphor (P-20), the scene presented to the viewer appears in shades or tones of green, and objects of similar luminance are difficult to distinguish from one another. Presenting a scene in color would increase contrast and aid in distinguishing objects. In addition, presenting a scene in true color has aesthetic value and might be less fatiguing to the observer than a monochromatic image.

The exact process by which the human visual system is able to translate light of different wavelengths into color sensations is not thoroughly understood. It is known, however, that an almost complete range of color sensations can be achieved by properly "mixing" light of the three additive primaries (blue-green-red).

The "quality" of a color image produced by a synthesized system depends upon three factors:

1. Brightness—the attribute of visual perception in accordance with which an area appears to emit more or less light.

2. Hue—The dominant wavelength, the attribute of colors that permits them to be separated into groups designated by such terms as red, green, blue, yellow, purple.

3. Saturation (tint: chromatic purity)—the attribute of visual color perception that can be described as pale, pastel, vivid, deep, etc.

In the experimental system, these factors depend upon the chromatic characteristics of the three output filter and upon the relative brightness of the three inputs to them. In a color

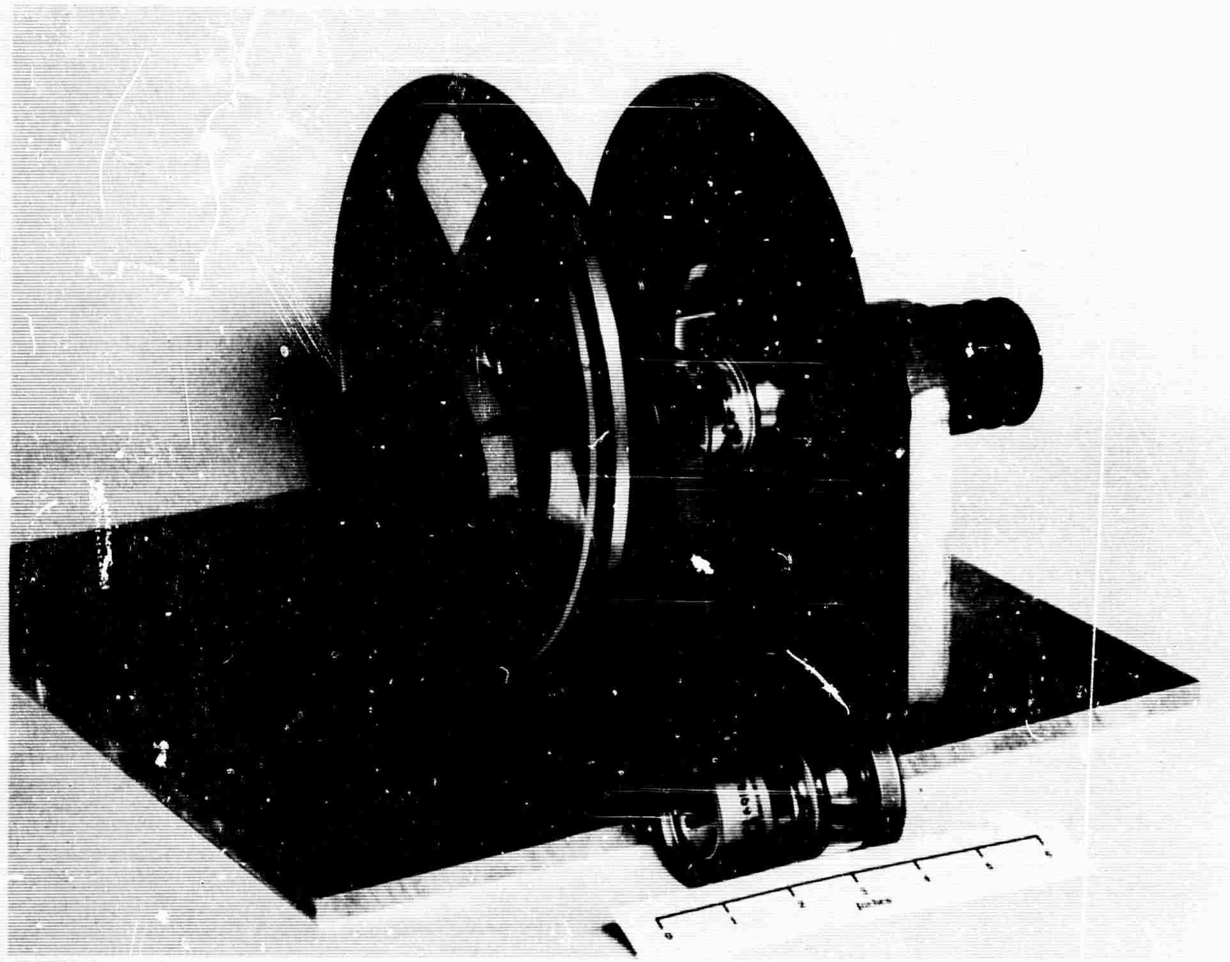

FIGURE 5. EXPERIMENTAL TEST FIXTURE

TV system, the relative brightness of the three primaries can be controlled electronically. With a color-viewing image-tube system, the problem must be handled by careful selection and balancing of the filter system.

In many applications, color fidelity is not as important a goal as it is in a color TV system. In fact, in some instances, the deliberate emphasis or de-emphasis of a certain hue may be advantageous.

In order to implement a color-viewing system, the Starlight Scope was mounted on the test fixture between the rotating filter holders.

Several problems were encountered in selecting a suitable set of input and output filters for the system. Both cellulose acetate and gelatin filters transmit freely beyond 6500 Å, in a region where an extended-red S-20 photocathode is still very sensitive. In order to avoid transmission in this region, we used sharp cutoff interference filters; these were glass filters (high-pass, low-pass) and were used in cascade to achieve a suitable bandpass characteristic. The transmission curves of the three sets of input filters used in this test are given in figure 6.

On the output end of the tube the near-infrared transmission characteristics of the cellulose acetate filters was not a problem, and this type filter was used. The major problem on the viewing end, however, was the narrow-spectrum green (P-20) phosphor present on all available tubes with which it was very difficult to achieve a relatively well-balanced red-green-blue output spectrum. Furthermore, since the obvious final solution of the problem would be to obtain a P-4 (white) phosphor, serious attempts at achieving optimum color balance could not be justified. However, by judicious selection from among the filters available and by visual observation of the end result, a set of output filters was selected which produced a reasonable compromise (see fig. 7).

A small d-c motor was used to drive the filters at speeds up to about 4000 rpm, although approximately 1500 rpm was found to be satisfactory at the light levels encountered. Slightly higher rotational speed would be required at brighter output levels to reduce flicker.

After a series of demonstrations, two conclusions were reached:

1. Colors could be reconstructed by the system, and target colors could be distinguished one from the other by all observers. Because of the filter-phosphor matching problem, however, color saturation varied across the spectrum to produce highly saturated reds and yellows, good blues, but poorly saturated greens.

2. The filters utilized in this test resulted in a severe loss of light output. Laboratory measurements indicate an overall light loss of approximately 8000×, which was broken down as follows:

a. Input filters and chopping loss ≈ 30×
b. Output filters and chopping loss ≈ 60×
c. Magenta phosphor correction filter ≈ 4.5×

Colors were easily discerned at an ambient light level of approximately 10^{-2} ft-L, although saturation was low. This level corresponds, approximately, to the ambient light level produced under full-moon conditions. This is also the approximate level at which the human eye changes over to its scotopic or "dark-adapted" state and suffers loss of color sense.

In order to achieve color imaging under starlight conditions, a good portion of this loss of 8000× would have to be recouped. Obtaining a tube with a white (P-4) phosphor to eliminate the

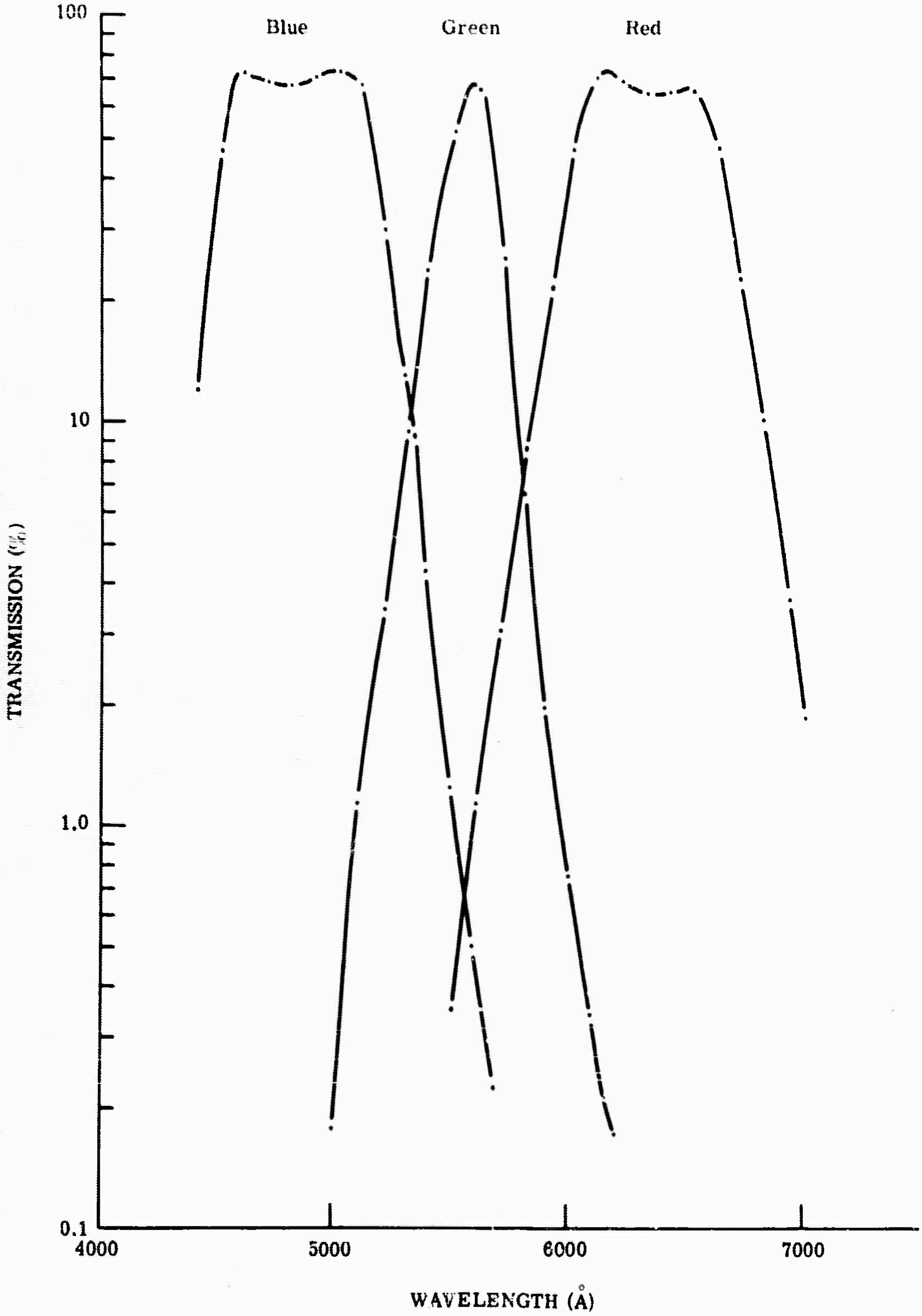

FIGURE 6. INPUT FILTER TRANSMISSION CHARACTERISTICS

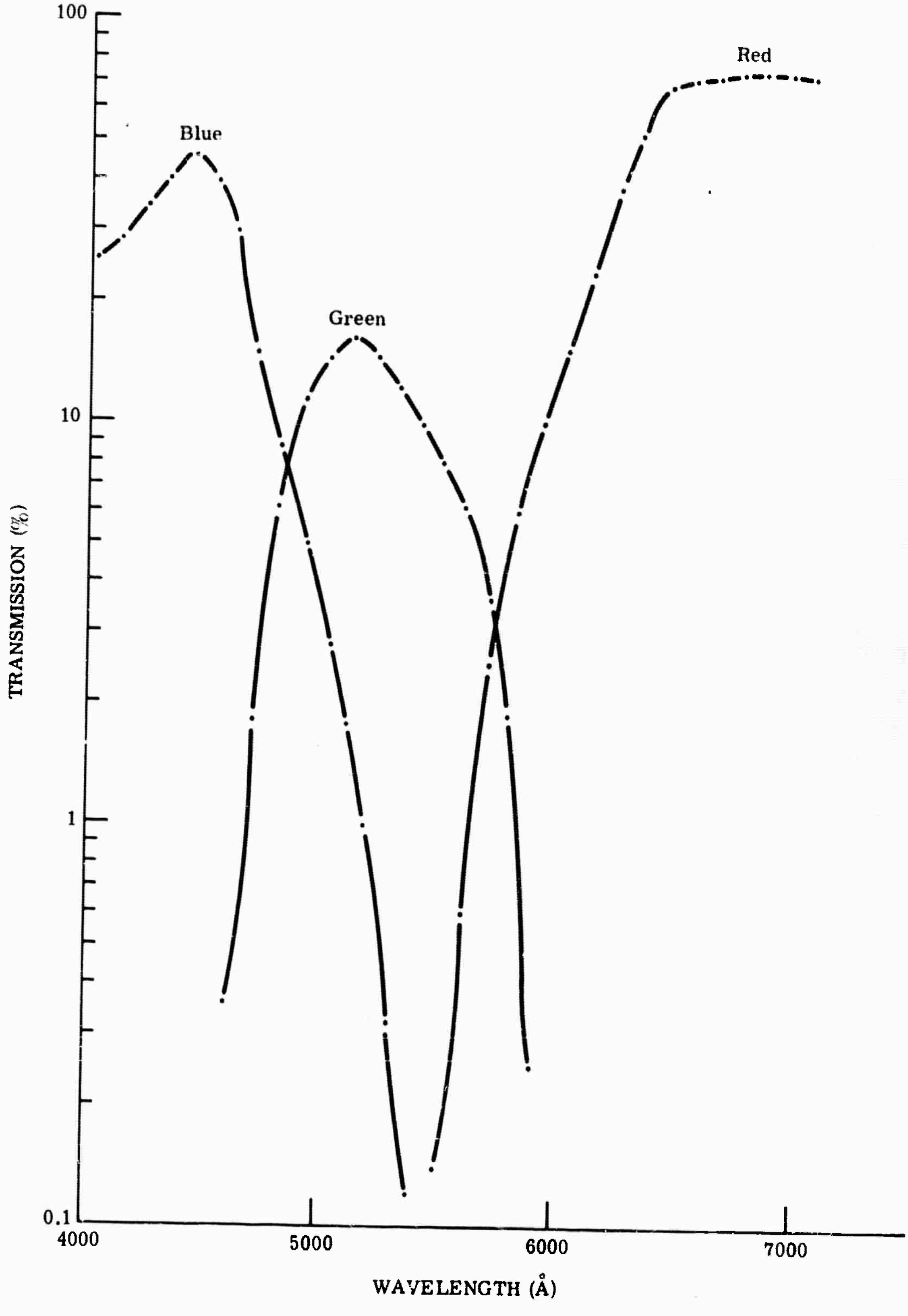

FIGURE 7. OUTPUT FILTER TRANSMISSION CHARACTERISTICS

magenta phosphor correction filter and rebalancing of the output filters should increase the light output by a factor of about 10.

Some of the remaining light loss might be compensated for by increased tube gain; however, at very low light levels, the image quality is limited by the randomness of photon arrival, and thus losses at the input (objective) end of the system are equivalent to true information loss. These losses cannot be recovered by additional gain. Higher gain can, however, be used to produce a brighter output image to overcome the output filter and chopping losses. The best that one can hope to do is evidently about 30 times worse than the Starlight Scope in terms of light gain. Thus, full-color imaging at starlight levels is doubtful.

Greater gain might be achieved by cascading additional stages; however, this would be costly and bulky and would result in further image degradation. One more stage would result in an unwanted image inversion. Two more results in more gain than is needed plus greater degradation, cost, and length. Second-generation intensification devices might be much more adaptable.

In summary, the experiments performed to date indicate that it should be possible to build a night vision aid capable of presenting color scenes under very low-light-level condition. Its performance under starlight conditions, however, would be limited by the statistical properties of photon arrival. In effect, the "signal-to-noise" ratio is very normally low at starlight levels and would be even worse with the filter system. At intermediate light levels equivalent to moonlight, color viewing may be feasible.

2.2. TRANSLATED COLOR SYSTEMS

The human eye as a visual sensor is sensitive in the region from about 4000 to about 7000 Å at best. It distinguishes objects one from the other by differentiating colors and/or shading within this spectrum.

Most objects, both natural and man-made, however, have unique reflection and absorption characteristics in this visible spectrum and beyond. Obviously, extending the spectrum of human vision would enable an observer to better sense his surroundings. (References 7 and 8 discuss areas of remote sensing and contrast enhancement by various means.)

Grass and green foliage around us offer a good example of a unique reflectance characteristic. Most healthy green foliage exhibits relatively low reflectance in the visible spectrum, peaking to about 15% at 5500 Å. It then shows a slight dip at about 6500 Å, due to chlorophyll absorption, and then reflects profusely (greater than 50%) in the region between 7500 and 14,000 Å. The greater portion of sunlight reflected from vegetation is invisible to the eye. Infrared photography takes advantage of this effect to produce very striking photographs enhancing the contrast between foliage and the surrounding scene. Reference 9 presents several infrared photographs showing typical "bright" foliage.

In order to extend the versatility of infrared photography, a sophisticated infrared color film was developed. A typical example of this type film is Kodak Infra-Red Aero type 8443. This film is a false or translated color film designed for aerial photography, although it has many other practical applications. It is sometimes referred to as camouflage detection (CD) film and is a three-color reversal film very similar to ordinary color film with two major exceptions:

1. The blue-sensitive layer has been replaced by an infrared-sensitive layer covering the range from about 7000 to 9000 Å.

2. The red-green and infrared-sensitive layers are printed out in a translated or false color scheme as shown in table I [10] (blue light is filtered before reaching the film).

TABLE I. INPUT-OUTPUT COLOR RELATIONSHIPS CD FILM

Sensitivity	Positive Layer	Print-Out
Red	Magenta	Green
Green	Yellow	Blue
IR	Cyan	Red

A picture taken with this type of film contains visual as well as the near-infrared components to enhance contrast and further aid in object discrimination. With this film, a khaki tank against foliage is reproduced as a blue-green tank against a red or pink background. Deciduous foliage appears a darker red than evergreen trees. This type of false-color film has found many applications in camouflage detection, forestry, geological surveys, and in other areas of science and industry.

An interesting application in the medical field uses this film to photograph venous patterns in order to increase the contrast of near-surface blood vessels against a flesh background to aid in diagnosis or to observe reactions. When viewed by the eye, arterial blood appears bright red, whereas venous blood appears much darker. Spectrophotometric reflection curves of oxygenated (arterial) and reduced (venous) blood are shown in reference 11. These curves indicate that a high contrast occurs in the spectrum from 6200 to 7500 Å, with arterial blood showing a dip in reflectance in this region and both showing high reflectance in the 5500-6000-Å region.

When photographed with infrared color film, arterial blood is recorded as yellow, whereas venous blood appears as a redish brown and in sharp contrast. When the reflectance of the blood is scattered by flesh, near-surface veins are recorded dark blue against a near-white or yellowish flesh background, and so are recorded with an increase in contrast. References 11 and 12 describe several medical and biological applications of IR photography.

By use of an image tube, it appeared feasible to assemble a relatively simple real-time viewer to parallel infrared photographic applications and to perhaps discover new ones.

Image tubes are not confined to the fixed-"bandwidth" red-green-infrared band separation of CD film. By rearrangement of input filters, an almost unlimited combination of color translations could be achieved, easily and on site. Furthermore, these activities can frequently be conducted in areas of sufficient illumination, so that filter-induced light losses are not a serious limitation.

In order to investigate the application of image tubes to false or translated color systems, the test fixture was configured as a "real-time" CD film system. The blue input filter was replaced by a near-infrared pass filter. The input-output filters were repositioned in accordance with table I, in order to produce a direct parallel of a CD film print.

By use of single-stage S-1 and S-20 photocathode tubes, the immediate area surrounding the Willow Run Laboratories was scanned at ground level. Observed target-background contrast was highly variable—a desirable feature. With near infrared translated to visible red as indicated in table I, grass and other vegetation appeared red or pink as viewed by both tubes.

The observed hue and relative brightness of other objects, however, varied and was dependent upon the photocathode used, the illumination, and the bandwidth of the three individual input filters. As previously mentioned, both tubes used in this series of demonstration tests had P-20 (green) phosphors and so color balancing was difficult.

The S-1 photocathode tube with its wider near-infrared sensitivity presented the most exaggerated effects, particularly when khaki and green objects were viewed against foliage backgrounds.

The S-20 photocathode tube with its higher sensitivity in the visible spectrum provided good overall color-translated scenes when used with a near-infrared filter cutting off at about 7500 Å. Its infrared response is sufficiently good to "catch" the near-infrared reflectance of grass and foliage while still providing visible-spectrum sensitivity. Using the S-20 tube along with narrowband green and red filters and the 7500-Å infrared filter, the contrast between military vehicles and foliage was improved dramatically. Evergreen trees were easily distinguished (dark red) from surrounding grass and deciduous trees (pink). Dead trees and grass appeared yellow against healthy (pink) specimens. Browns, blacks, yellows, grays, and whites appeared in a good approximation to their normally observed hue. Dirt and gravel paths appeared in good contrast to the surrounding grass. Blues, of course, appeared very dark since they were rejected by the input filters. Reds and greens were translated into poorly saturated but distinguishable green and blue, respectively, again because of the phosphor-filter balancing problem. Using a narrowband red (6500-Å) filter and a broadband blue-green filter (4500-5500-Å), along with the 7500-Å infrared pass filter, outdoor scenes were viewed in nearly true color while retaining the "pink foliage" feature. This latter configuration allowed good contrast between foliage and military targets while most other objects remained in nearly true color.

It should be pointed out that most tests were conducted under clear or partly cloudy conditions, although color-translated targets were discernible under heavily overcast skies (10^2 to 10^3 ft-L). Even more dramatic effects would have been observed if higher gain white phosphor tubes had been available.

Painted and dyed targets presented very interesting color translations since their reflectance characteristics were not known beforehand. In one instance a weathered pale blue trailer was found to be a very good reflector of near infrared and appeared pink, whereas a darker blue truck alongside appeared almost black. In another instance a Willow Run Plant Department truck was viewed. The cab and body which appeared visually to be well-matched blue were translated into a maroon cab and black body. Further investigation revealed that the body had been repainted two years previously with paint from a different manufacturer. In several instances certain items of clothing proved to be profuse reflectors of near-infrared energy.

Unfortunately, circumstances did not permit aerial observations of forested areas, mineral deposits, populated areas, etc. Since the breadboard system lacked portability, objects and scenes viewed were very limited.

The medical aspect was briefly looked into and was confined to viewing a forearm in order to determine if near-surface veins could be more clearly seen. The conclusion drawn from this simple experiment was that the contrast was enhanced although the process was not optimized for best contrast, primarily because of poor lighting.

The results of these preliminary tests were extremely revealing and indicate that a portable real-time viewer should prove to be a useful device, especially if a higher gain white phosphor tube were utilized.

3
RECENT RESULTS

The directly viewed image-intensifier tube does not, even at its best, produce a particularly bright image. Also, it is small and normally is viewed through a rather wide-angle eyepiece. These all contribute to making it relatively difficult to obtain a good photographic record of the output using casually available photographic equipment. In the case of the work just described, the output image was, in fact, quite dim because of the large light-intensity losses discussed earlier.

Very recently we have managed to obtain some fairly good color photos through the test system. These were taken with a 35-mm single-lens reflex camera. The eyepiece was removed, and the image was photographed directly; extension tubes and a lens-reversing adapter were used. The image on the film was roughly 1.5× to 2× larger than the image on the intensifier.

Typic exposures were 4 sec at f/2.0 on High Speed Ektachrome. These are best viewed as projected slides; however, enlarged prints have also been made; see several examples at the end of this report.

The first series of photographs was taken indoors by artificial light. The subject was a multicolored label (from a Krylon can) which bore a group of large discs of five distinctive colors (see color print 1). In this case, the filters were bandpass red, blue, and green with no intentional sensitivity outside the visible spectrum. The viewing-filter colors corresponded to the input filters, so that reaso bly true-color rendition would be obtained. A magenta filter was also included at the viewing end to help balance th predominately green P-20 phosphor.

The rest of the pictures were taken outdoors by natural illumination. For these, the filters were selected to reproduce the approximate characteristics of CD film as discussed above.

4
FUTURE PROGRAM

The experimental work which has been described was done as part of the night vision aids program under this contract. The support was necessarily quite limited and was only intended to carry the work far enough for an initial assessment of the feasibility and potential value of the technique. It has been shown that image intensifiers can be used to obtain true-color viewing at light levels below those providing normal unaided color vision. More important, it has been shown that real-time color-translation can be used to enhance certain target characteristics which lie outside the normally visible spectrum.

It appears feasible to achieve the performance characteristics of CD film in real time and to be able to vary the spectral response at will to enhance specific characteristics. This should be valuable in military reconnaissance and surveillance as well as in other fields that have found CD film to be of value. These range from medical diagnoses to forestry surveys.

The next step should be to institute a program which includes both experimental hardware and the study and analysis of available multispectral data. The program should include:

1. A review of the available multispectral reflectivity data at Willow Run Laboratories to estimate the performance to be expected with interesting target-background combinations. This would include both military and nonmilitary applications.

2. A continuing effort to keep abreast of the most recent developments of image tubes and their applications.

3. A continuing invest ation of present uses of imaging in nonvisible spectral regions in medical, geological, forestry, and other fields.

4. Construction of a higher quality, more flexible, and more portable model for continuing experimental work. This should include acquisition of a high-performance intensifier having a white phosphor and an S-20 photocathode. This system should be suitable for field observation, both ground based and airborne.

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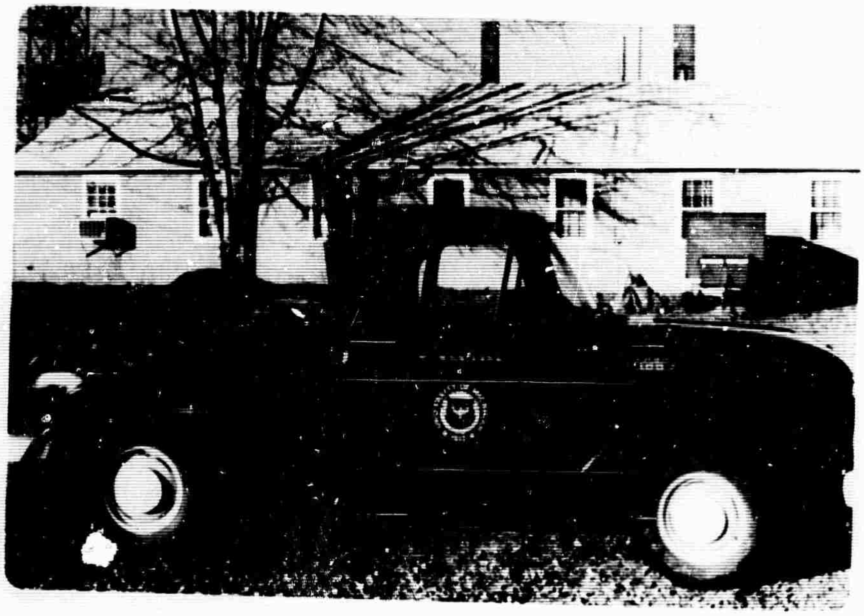
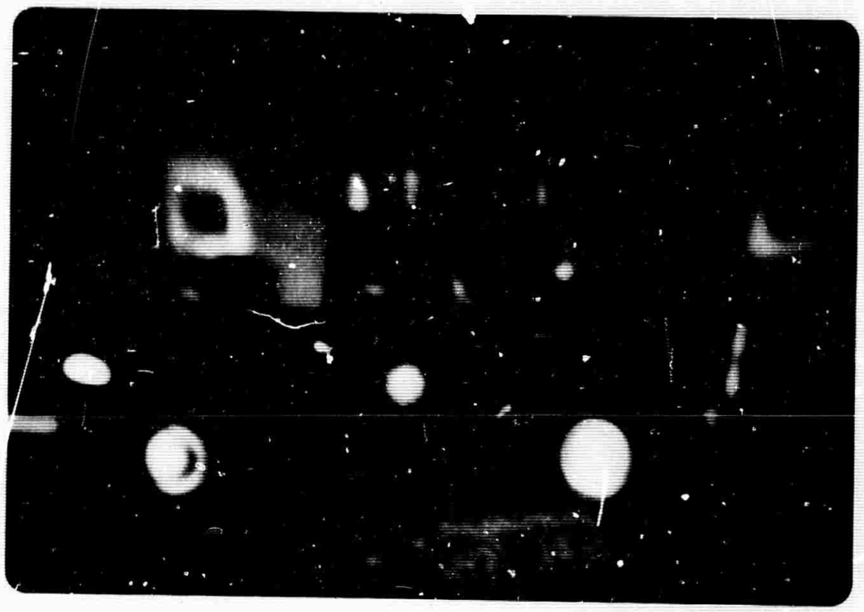
COLOR PRINT 1

Typical true-color result using red, blue, and green filters. The colors arc reasonably faithful reproductions of the original, although saturation is somewhat reduced. This may be due to phosphor decay being too slow or to the remaining sensitivity to the near infrared.



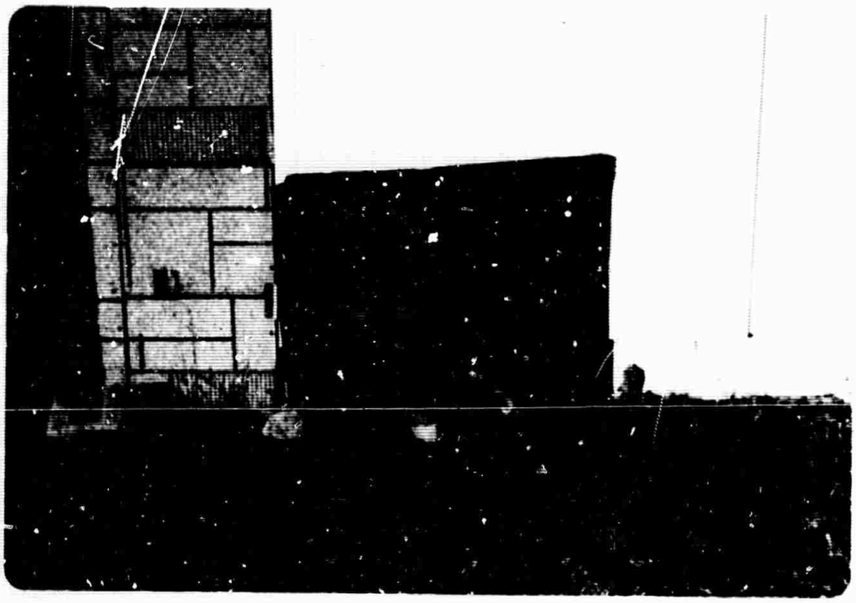
COLOR PRINT 2

This is a direct photo of a University-owned truck which has been partially repainted. All the paint appears blue, but it can be seen that the cab and top of the hood are darker. We have no specific information regarding the two kinds of paint.



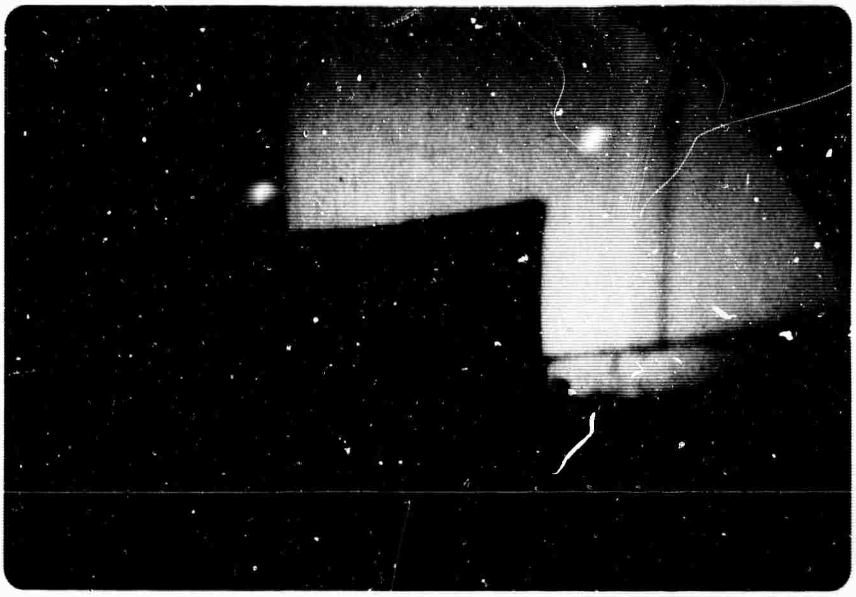
COLOR PRINT 3

This is the same truck shown in Color Print 2, as viewed with the intensifier with the filters selected to reproduce the characteristics of CD film. The cab and hood top are seen to be reddish, indicating significant near-infrared reflectance. The remainder of the truck is dark and rather blue, indicating low predominately green reflectance.



COLOR PRINT 4

This is a direct photo of a philodendron plant against a dark green cloth background. The paint and cloth match fairly well in the visible spectrum. Picture taken in late fall after much of the grass had died



COLOR PRINT 5

This is the same plant shown in Color Print 4 as seen through the intensifier system. The filters were selected to reproduce the characteristics of CD film. Note the extreme contrast between plant and background. Grass which was still green now appears red; however, dead grass does not. Both effects are due to the large near-infrared reflectance of green foliage.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Willow Run Laboratories of the Institute of Science and Technology The University of Michigan, Ann Arbor	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

USE OF IMAGE INTENSIFIERS FOR REAL-TIME VIEWING

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

C. Paprocki and R. Miller

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1968	viii + 24	12

8a. CONTRACT OR GRANT NO. DA-44-009-AMC-1494(T) b. PROJECT NO. ARPA Order 774 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 7919-26-T 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Va.

13. ABSTRACT

An experimental program has investigated the practicality of synchronized rotating filter wheels at the input and output of an image intensifier to produce a field-sequential color image. Both military and commercial intensifier tubes were used. Reasonably true-color rendition was obtained, even with the limitations imposed by crude equipment and far-from-optimum filters. Fundamental limitations result in rather large energy losses and hence preclude full-color operation at very low light levels (such as starlight). At intermediate light levels, color viewing may be practical and may be valuable in enhancing target contrast.

With appropriately chosen sets of input and output filters, the spectral response of camouflage detection film can be duplicated. This makes the near-infrared reflectance of the scene visible by translating that portion of the spectrum to visible red. Red input energy is presented as green in the image, and green input is presented as blue. These translations make green vegetation appear in striking contrast to man-made objects which to the unaided eye seem to match closely. This suggests the possible use of this simple device for real-time reconnaissance, with appropriately chosen filters and spectral translations to enhance specific target classes. The obvious advantage over camouflage detection film is that this device operates in real time. Also, the spectral translation characteristic may be readily varied.

The promising experimental results suggest that a supplemental program should be supported: a better, more flexible, and more portable model should be built; and available spectral reflectance data should be analyzed to help select optimum filter combinations.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Image tubes						
Image intensifiers						
Real time						
Multispectral viewing						
Photography						
Color photography						
Infrared photography						